MPX Image Analyser – User Guide

1   Introduction

The MPX Image Analyser (MIA) reads in data that has been measured on an MPX Modal Explorer. It then computes the Mode Power Distribution (MPD) and uses this to compute the loss between two offset fibres.

Version 1.0 of MIA has the following restrictions:

Assumes circular fibres
Assumes both fibres are the same diameter and NA.

2   Software package

MIA is a Visual Basic (VB6) program and utilises reference mode-field data that has been previously computed in Mathcad. The required files for MIA to work are as follows:

EFSA.vbp
EFSA.frm
EFSA.bas   or EFSA.exe
Frmabout.frm

weights.csv
X.prn   computed using Mathcad
Inv.prn

The source Mathcad files are:

Laguerre.MCD
Overlap.MCD

3   Software operation

Load and run EFSA.vbp, select 'load data' and choose an MPX-1 data file to read. The data will be computed and the screen should look like the figure below.

The image, top left, is the MPX bitmap.

EF is the computed EF, according to latest (2009) versions of IEC61280-1-4 and FOTP-203.

MPD is the Mode Power Distribution, computed from the near-field intensity profile, according to FOTP-220.

NF shows the measured near-field intensity profile in red, taken as the average of four diameters at 45° angles through the bitmap image. The green profile is the near-field regenerated from the MPD. This is given as a diagnostic to check that the MPD is correct. Selecting the checkbox shows the difference between the red and green curves, magnified by x10.
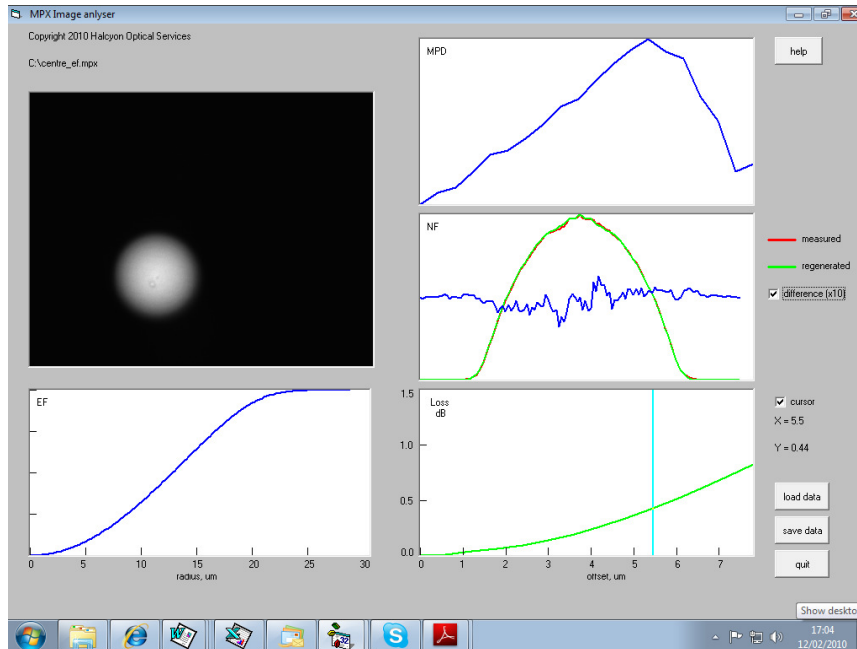
Loss shows the computed loss due to offset between two identical fibres, where the source (input) fibre has the MPD shown above. Note that losses due to Fresnel reflection at the fibre interfaces are not included in the model. A cursor is provided to read the loss vs offset data.

The 'save data' button allows the computed loss data and to be saved to disc. This is identified by the file extension .LOSS.

The 'quit' button exits the software.

4   Detailed operation

4.1   Compute the Laguerre-Gauss modes in Mathcad

The Mathcad program 'Laguerre.MCD' computes the complete guided mode-set for a parabolic graded-index fibre. The electric field E as a function of mode number (η,μ) is given by the time-independent Helmholtz equation, as follows:

$$E_{\eta,\mu}(\rho,\phi,z) = \rho^{\eta}e^{\frac{-\rho^2}{2}}L_{\mu-1}^{\eta}(\rho^2)\sin(\eta\phi+\theta_o)e^{-j(\beta z)} \tag{1}$$

where ϕ is azimuthal angle, z is position along the fibre and ρ is a radial variable given by

$$\rho = \frac{r}{a}\sqrt{V} \tag{2}$$

where a is the fibre radius and V is the normalised frequency, given by

$$V = ak_o NA \tag{3}$$

and

$$L_{\mu'}^{\eta}(\rho^2) = \sum_{s=0}^{\mu'} \frac{(\mu'+\eta)!(-1)^s \rho^{2s}}{(\eta+s)!(\mu'-s)!s!} \tag{4}$$

is the generalised Laguerre polynomial, where, for convenience, the substitution $\mu'=\mu$-1 has been made. θ_o= 0 or $\pi/2$, represents pairs of degenerate modes when $\eta\neq0$, these are cosine and sine functions.

In the Mathcad program, 'Field1' and 'Field2' represent the complete set of cosine and sine mode-field solutions. These are saved to disc as 'Parafield1.prn' and 'Parafield2.prn'.

The default parameters are:

Fibre diameter:	50um
Wavelength:	0.85um
NA:	0.21
Cladding index:	1.457
Grid size:	121x121 points
Grid range:	72um
Grid spacing:	0.6um

4.2   Compute the mode overlap integrals in Mathcad

Mathcad program "Overlap.MCD' computes the overlap between each and every mode-field in the source (input) fibre with each and every mode-field in the target (output) fibre.

Firstly, the mode-field solutions computed above are read in as Parafield1 and Parafield2. These are then offset across the 121x121 grid by an amount given by the parameter 'offset', which must be in multiples of 0.6um, to match the grid spacing. The resultant mode-field sets are called P1_os and P2_os.

The mode overlap factor ε is given by

$$\varepsilon = \frac{\int\int E_S(x,y)E_T(x,y)dxdy}{\sqrt{\int\int E_S(x,y)E_S(x,y)dxdy}\sqrt{\int\int E_T(x,y)E_T(x,y)dxdy}} \tag{5}$$

where E_S and E_T are the mode-fields of the source and target fibres respectively.

The mode overlap factor can take values from zero, in the case of no overlap, to unity for complete overlap.

There are four subroutines to compute eqn. (5). These are of the form 'Overlap1(a,b)' and correspond to the overlap between the sine and cosine fields in the source fibre with the sine and cosine fields in the target fibre. The overlap factors are then summed into their corresponding mode groups to give OS1_sum which is the MPD of the target fibre A fully-filled source fibre is assumed for the source fibre, given by MPD(m)=m, where m is the mode group number.

The calculation has been repeated for a range of offsets from zero to 7.8um and the resulting MPD's are saved in a file called 'weights.csv' which is required by the VB program.

It has been found that is not necessary to carry out the overlap calculation for each source MPD used. Instead, the same loss result is obtained by multiplying the fully-filled MPD values in 'weights.csv' by the MPD of the source fibre. This means that the overlap integrals vs offset only have to be computed once to set up 'weights.csv'.

Data required for the VB program to work is saved at the foot of the Mathcad program. These are a 'design' matrix called 'X.prn' and an intermediate matrix called 'Inv.prn', these are required to compute the MPD from the measured MPX data.

4.3   Computation of the MPD in MIA

The total power in a mode group m is given by

$$P_g(m) = \sum_{\mu=1}^{int[(m+1)/2]} \left[\left(E_{\eta,\mu} \right)^2_{\theta_o=0} + \left(E_{\eta,\mu} \right)^2_{\theta_o=\pi/2} \right] \tag{6}$$

where $\eta = m+1-2\mu$.

Then the total power in the fibre P_{tot} is given by

$$P_{tot} = \sum_{m=1}^{M} \left[P_g(m) \cdot MTF(m) \right] \tag{7}$$

where M is the total number of mode groups and MTF(m) is the Mode Transfer Function and is given by

$$MTF(m) = \frac{MPD(m)}{m} \tag{8}$$

The MTF may be computed by matrix manipulation (FOTP-220), as follows

$$MTF(m) = \left[P_g(m) \right]^{-1} P_{tot} \tag{9}$$

In order to improve the stability of eqn. (9) a method called 'Singular Value Decomposition' (SVD) is used in MIA, as follows

$$MTF = \left[P_g{}^T P_g \right]^{-1} \left[P_g{}^T P_{tot} \right] \tag{10}$$

In 'Overlap.MCD' the term $P_g(m)$ is given by 'X.prn' and the inverse term is given by 'Inv.prn'. P_{tot} is the measured near-field intensity profile.

4.4   Computation of loss in MIA

The loss for a range of offsets i is given by

$$\text{loss}_i = 10 \log \left[\frac{\sum_m \text{MTF}(m) \cdot \text{MTF\_FF}_i(m) \cdot m}{\sum_m \text{MTF}(m) \cdot \text{MTF\_FF}_0(m) \cdot m} \right] \qquad (11)$$

where MTF(m) is the MTF computed in eqn. (10) and $\text{MTF\_FF}_i(m)$ is the MTF in the target fibre for an offset i when the source fibre is fully-filled. A table of $\text{MTF\_FF}_i(m)$ is stored in the file 'weights.csv' for use by MIA. $\text{MTF\_FF}_0(m)$ is the MTF in the target fibre at zero offset.

5   Default Parameters

The default parameters for the Mathcad computations are given in section 4.1. If any of these is changed it important to recompute the following:

The Laguerre mode-fields in 'Laguerre.MCD' and save as 'Parafield1.prn' and 'Parafield2.prn'

The overlap integrals in 'Overlap.MCD' and save as 'X.prn' and 'Inv.prn'. Also need to set up a new 'weights.prn' matrix.

and also change the constants in EFSA.bas, accordingly

```
Public Const MCnum = 120    'the size of the mode-field grid minus 1
Public Const MCrange = 36   'the half range of the grid in um
Public Const Ng = 18        'the number of mode groups minus 1
Public Const fibrediam = 50 'the fibre diameter in um
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